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Recent trends in nutrigenomics and personalized diet: A mini review

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Abstract

Nutrigenomics, encompassing both nutrigenomics and nutrigenetics, is an evolving discipline that investigates the interaction between dietary components and the human genome, providing insights into how nutrition influences gene expression and disease risk. With the global increase in chronic conditions such as obesity, diabetes, cardiovascular disease, and cancer, personalized nutrition based on genetic profiles has emerged as a promising approach to health promotion and disease prevention. This review aims to provide a comprehensive overview of recent advances in nutrigenomics and personalized diet strategies. A structured literature search was conducted using PubMed, Scopus, and Web of Science, focusing on publications between 2015 and 2024. Key findings indicate that specific genetic variants (e.g., *FTO*, *APOE*, *MTHFR*) significantly modulate individual responses to macronutrients and micronutrients, influencing metabolic pathways, inflammation, and oxidative stress. Bioactive compounds such as polyphenols, omega-3 fatty acids, and vitamins have been shown to regulate gene expression through epigenetic mechanisms including DNA methylation, histone modification, and microRNA modulation. The integration of omics technologies—genomics, transcriptomics, proteomics, metabolomics, and microbiomics—has enhanced the understanding of complex gene-diet interactions. Furthermore, artificial intelligence and machine learning applications are enabling predictive models for precision nutrition by combining genetic, dietary, and lifestyle data. Despite its promise, challenges remain, including the need for large-scale longitudinal studies, ethical concerns related to genetic data privacy, and barriers to clinical translation. Overall, nutrigenomics represents a paradigm shift from generalized dietary guidelines toward individualized nutrition care, with the potential to significantly reduce the burden of chronic disease and improve population health outcomes.

Keywords: Nutrigenomics, nutrigenetics, personalized diet, gene-nutrient interaction, precision nutrition

Introduction

The relationship between diet and health has been recognized for centuries, but recent advances in molecular biology and genomics have profoundly transformed our understanding of how nutrients influence gene expression and disease susceptibility ^[1, 2]. Nutritional genomics, also known as nutrigenomics, investigates the mechanisms through which dietary bioactive compounds regulate molecular pathways such as inflammation, oxidative stress, lipid metabolism, and glucose homeostasis ^[3, 4]. Closely related to this is nutrigenetics, which examines how genetic variations alter nutrient metabolism, absorption, and utilization, thereby explaining the wide inter-individual variability observed in dietary responses ^[5, 6]. Together, these fields form the basis of personalized nutrition, an approach that adapts dietary interventions to an individual's genetic profile, lifestyle, and environmental exposures ^[7, 8].

Nutrigenomics primarily focuses on the influence of nutrients on gene activity, including transcriptional regulation and epigenetic mechanisms. For instance, polyphenols found in grapes and green tea can regulate microRNAs associated with cancer progression ^[9], while omega-3 fatty acids modulate the expression of genes involved in inflammatory pathways ^[4]. In contrast, nutrigenetics seeks to identify genetic polymorphisms that modify responses to dietary components. Well-studied examples include the *APOE* gene variant, which influences lipid metabolism and dietary fat recommendations ^[10], and mutations in the *MTHFR* gene, which affect folate metabolism and cardiovascular risk ^[11].

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The significance of these insights is particularly evident in the context of public health. Chronic diseases such as obesity, type 2 diabetes, cardiovascular disorders, and cancer account for the majority of global mortality and are strongly shaped by dietary habits [12, 13]. Conventional dietary guidelines are typically based on population averages and often fail to account for genetic diversity. By contrast, nutrigenomics offers a scientific foundation for shifting from a one-size-fits-all dietary framework to personalized nutrition, thereby enhancing both preventive and therapeutic strategies [14, 15]. This personalized approach is especially valuable in genetically diverse populations and regions with wide variations in dietary practices, such as Asia and Africa [16].

Recent technological advances have further accelerated progress in this field. The development of next-generation sequencing, whole-genome sequencing, and advanced bioinformatics platforms has enabled the rapid identification of diet-related genetic markers [17]. Complementary approaches such as metabolomics, transcriptomics, and microbiome analysis now provide a systems-level view of the interactions between diet and gene networks [18, 19]. Moreover, the incorporation of artificial intelligence and machine learning into nutritional genomics has made it possible to analyse large datasets that integrate genetic, clinical, and dietary information, thereby facilitating predictive models of individual dietary responses [20, 21]. The emergence of wearable devices and mobile health applications that monitor diet, physical activity, and biomarker fluctuations has also contributed to the real-time application of precision nutrition strategies [22].

The applications of nutrigenomics are broad and hold significant promise. In disease prevention and management, personalized diets can help reduce risk factors associated with metabolic syndrome, cardiovascular diseases, and cancer by modulating gene activity [2, 4, 23]. In sports nutrition, genetic insights into muscle fiber composition, energy metabolism, and recovery patterns enable the optimization of dietary strategies to enhance athletic performance [24]. In the context of aging and longevity, epigenetic mechanisms influenced by caloric restriction and diets rich in antioxidants may delay the onset of age-related diseases [25]. Furthermore, the field contributes to the development of functional foods and nutraceuticals designed to address specific genetic vulnerabilities, such as probiotics for gut health or folate-enriched diets for individuals with *MTHFR* polymorphisms [11, 23].

Despite these advances, nutrigenomics faces several challenges. Gene-diet interactions are complex, often influenced by multiple environmental and lifestyle factors, which makes replication across populations difficult [5, 14]. Ethical concerns related to genetic testing, including issues of privacy, data ownership, and potential misuse of genetic information for discriminatory purposes, must be carefully addressed [24]. In addition, the limited accessibility of genetic testing in low- and middle-income countries raises concerns of health inequity, as the benefits of personalized nutrition may remain confined to affluent populations unless efforts are made to democratize these technologies [25].

Given the rapid expansion of nutrigenomic research and its potential to revolutionize nutrition and healthcare, this review aims to provide a comprehensive synthesis of current evidence on gene-nutrient interactions and personalized dietary interventions. It also seeks to highlight technological

advances in omics, bioinformatics, and artificial intelligence that are shaping the future of nutritional science, to discuss clinical and public health implications along with ethical and translational challenges, and to offer perspectives on integrating nutrigenomics into healthcare systems as a key component of precision medicine [1, 7, 19].

Materials and Methods

Literature Search Strategy

A structured literature search was conducted to identify peer-reviewed articles focusing on nutrigenomics, nutrigenetics, and personalized diet interventions. Major databases including PubMed, Scopus, Web of Science, and Google Scholar were searched for relevant publications between January 2015 and May 2024. Search terms included combinations of keywords such as nutrigenomics, nutrigenetics, gene-nutrient interaction, personalized nutrition, precision diet, omics technologies, and microbiome. Reference lists of selected articles were also screened to capture additional relevant studies.

Inclusion and Exclusion Criteria

Studies were included if they

1. Reported original research, systematic reviews, or meta-analyses related to nutrigenomics or nutrigenetics.
2. Examined gene-diet interactions in humans or animal models relevant to chronic disease prevention or dietary interventions.
3. Discussed emerging technologies such as genomics, metabolomics, proteomics, or microbiome analysis in relation to nutrition.

Exclusion criteria were

1. Non-peer-reviewed articles, editorials, or opinion pieces without supporting data.
2. Studies published in languages other than English.
3. Articles unrelated to nutrition-gene interactions

Study Selection and Data Extraction

The search initially retrieved approximately 100 publications. After screening titles and abstracts, 85 full-text articles were reviewed. Following application of inclusion/exclusion criteria, 25 studies were included for detailed synthesis. Data extracted from each study included study design, population/sample, genetic variants studied, dietary interventions, outcomes assessed, and major findings.

Quality Assessment

Systematic reviews and clinical studies were prioritized, while case reports and pilot studies were considered where they provided novel mechanistic insights. To ensure reliability, studies were evaluated based on sample size, methodological clarity, and reproducibility of findings.

Synthesis Approach

A narrative synthesis was employed due to heterogeneity across studies in terms of design, biomarkers assessed, and outcome measures. Findings were grouped under major themes:

1. Gene-nutrient interactions and chronic disease outcomes.
2. Nutrigenomic influence of bioactive compounds and dietary patterns.

3. Integration of omics technologies in nutrition science.
4. Role of gut microbiome in shaping dietary response.
5. Emerging role of AI and digital health tools in personalized diet planning.

Results

Gene-Nutrient Interactions in Chronic Disease

The literature consistently demonstrates that genetic polymorphisms influence individual responses to diet, thereby modifying disease susceptibility. Variants in the fat mass and obesity-associated (*FTO*) gene are strongly associated with obesity and altered energy metabolism. Carriers of risk alleles tend to have higher energy intake and reduced satiety, but lifestyle interventions such as calorie restriction and exercise can attenuate these effects. Similarly, polymorphisms in the apolipoprotein E (*APOE*) gene affect lipid metabolism and cardiovascular disease risk, with *APOE* $\epsilon 4$ carriers showing greater sensitivity to saturated fat intake. Another well-studied variant is in the methylenetetrahydrofolate reductase (*MTHFR*) gene, which alters folate metabolism and elevates homocysteine levels, thereby increasing cardiovascular risk. These findings highlight the importance of tailoring dietary recommendations to genetic predispositions.

Role of Bioactive Compounds in Gene Regulation

Bioactive food compounds exert significant nutrigenomic effects by modulating signaling pathways and epigenetic markers.

- Polyphenols, such as resveratrol (grapes), curcumin (turmeric), and epigallocatechin gallate (green tea), have been shown to regulate microRNAs and influence pathways related to inflammation and carcinogenesis.
- Omega-3 fatty acids modulate the expression of genes involved in lipid metabolism and reduce inflammatory responses, offering protection against cardiovascular and autoimmune diseases.
- Vitamins and minerals also act as key regulators; for instance, vitamin D interacts with vitamin D receptor (VDR) polymorphisms to influence bone health and immunity.

These results emphasize that dietary components act not merely as sources of energy but as modulators of gene expression.

Integration of Omics Technologies

The application of multi-omics platforms has significantly advanced nutrigenomic research.

- Genomics and transcriptomics reveal associations between genetic variants and dietary responses.
- Proteomics identifies protein biomarkers altered by diet, particularly those linked to metabolic syndrome and diabetes.
- Metabolomics captures real-time changes in metabolites such as amino acids, fatty acids, and lipids, providing insight into nutrient utilization.
- Microbiomics has highlighted how gut microbial composition mediates host gene expression and metabolic health.

The integration of these datasets through systems biology approaches allows for comprehensive mapping of diet-gene-phenotype interactions.

Role of the Gut Microbiome

The gut microbiome has emerged as a central mediator of diet-gene interactions. Variations in microbial composition influence nutrient absorption, energy harvest, and immune regulation. For instance, individuals with higher ratios of Firmicutes to Bacteroidetes are more prone to obesity. Diets rich in fiber increase short-chain fatty acid (SCFA) production, which modulates host gene expression related to inflammation and insulin sensitivity. Recent studies suggest that microbiome signatures can be used to predict individual glycemic responses to food, reinforcing the role of microbiota in personalized nutrition strategies.

Emerging Role of Artificial Intelligence and Digital Health

Artificial intelligence (AI) and machine learning (ML) are increasingly applied to analyze complex nutrigenomic data. By integrating genetic, microbiome, metabolomic, and dietary intake data, AI algorithms can generate predictive models for personalized dietary recommendations. For example, ML-based dietary scoring systems have been shown to predict postprandial glucose responses more accurately than conventional glycemic index values. Moreover, digital health tools such as smartphone applications and wearable devices enable real-time monitoring of diet, activity, and metabolic markers, making personalized nutrition accessible at the population level.

Discussion

Interpretation of Findings

This review highlights how nutrigenomics and nutrigenetics have transformed our understanding of the diet-gene relationship. Evidence demonstrates that genetic variations such as *FTO*, *APOE*, and *MTHFR* polymorphisms significantly affect metabolic responses to nutrients. This underlines why population-based dietary guidelines often fail to achieve optimal outcomes at the individual level. Personalized dietary interventions, informed by genetic and epigenetic data, have shown promise in mitigating risk for obesity, cardiovascular disease, diabetes, and cancer.

Moreover, bioactive compounds are not only nutrient sources but also gene regulators. Polyphenols, omega-3 fatty acids, and vitamins exert epigenetic modifications that influence inflammation, oxidative stress, and cellular metabolism. These findings support the concept of functional foods and nutraceuticals tailored to genetic profiles, bridging basic nutrition science and clinical application.

The integration of multi-omics technologies provides a comprehensive systems-level approach, combining genomics, metabolomics, proteomics, and microbiomics. This convergence enhances the predictive capacity of nutrigenomics and enables a shift from reactive disease treatment toward preventive, precision nutrition strategies.

Clinical and Public Health Implications

Personalized nutrition has the potential to reshape clinical nutrition practice. For example, genetic testing for *MTHFR* polymorphisms can guide folate supplementation to reduce cardiovascular risk, while *APOE* profiling can help determine optimal fat intake in individuals at risk of hyperlipidemia. Beyond clinical care, nutrigenomics can improve public health strategies by tailoring interventions to populations with specific genetic susceptibilities.

The role of the gut microbiome further underscores the complexity of nutrition science. Microbial signatures predict glycemic responses more reliably than macronutrient content alone, offering a new dimension to dietary recommendations. Personalized diets incorporating microbiome analysis may thus provide novel solutions for managing metabolic diseases.

Technological and Ethical Considerations

While artificial intelligence and machine learning enhance predictive accuracy, they introduce concerns regarding transparency, bias, and data security. Genetic and microbiome data are highly sensitive, raising ethical questions about privacy, ownership, and potential misuse by insurers or employers. Therefore, establishing clear legal and ethical frameworks is crucial for responsible application of nutrigenomic findings.

Accessibility also remains a challenge. The cost of genetic sequencing and advanced diagnostics restricts the benefits of nutrigenomics to high-income populations, risking the widening of health disparities. To achieve global impact, nutrigenomic tools must become affordable, scalable, and culturally adaptable.

Conclusion

Nutrigenomics and nutrigenetics represent a paradigm shift in nutrition science, moving from generalized dietary guidelines toward precision nutrition tailored to individual genetic, metabolic, and microbial profiles. The evidence reviewed highlights that specific genetic variants, bioactive dietary compounds, and microbiome diversity collectively influence nutrient metabolism, disease susceptibility, and therapeutic outcomes. Integration of multi-omics technologies, coupled with advances in artificial intelligence and digital health, is accelerating the translation of nutrigenomic research into personalized dietary strategies.

Despite this progress, several barriers remain. The complexity of gene-diet interactions, limited availability of long-term clinical trials, and lack of standardized methodologies continue to challenge the field. Ethical concerns regarding data privacy, equity of access, and potential misuse of genetic information must also be addressed before nutrigenomics can be fully integrated into healthcare systems.

Looking ahead, nutrigenomics holds immense promise for disease prevention, management of chronic conditions, and optimization of health across diverse populations. Large-scale validation studies, robust ethical frameworks, and multidisciplinary collaboration will be critical in realizing this potential. As technology advances and becomes more accessible, personalized diets informed by genomic insights are likely to become an integral component of preventive medicine and public health strategies.

In summary, nutrigenomics is no longer a futuristic concept but an emerging reality in clinical and public health nutrition. Its successful implementation could significantly reduce the global burden of chronic diseases and contribute to healthier, longer lives.

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